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Development of robot motion direction based on microcontroller with compass sensor

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ABSTRACT

This research brings innovation to the motion and navigation system of the 'DK-ONE' robot. In the 2021 Indonesian 'Search and Rescue' robot contest, the 'DK-ONE' robot faced difficulties moving towards the target room. The issue was attributed to an unbalanced frame construction and friction between the robot's legs and the arena floor, leading to leg slippage. This resulted in a mismatch between the programmed number of steps for the robot and the desired path to the target space, causing errors in the robot's system. To address these problems, researchers conducted a study aimed at enabling the 'DK-ONE' robot to accurately determine its direction of motion. This research followed the waterfall method, involving stages such as system analysis, design, coding, testing, and supporting phases. The study was carried out in the integrated laboratory of the Department of Electrical Engineering Education. The development of the robot's motion direction using a compass sensor significantly improved stability while walking on straight, flat, and uneven paths. The robot no longer experienced errors in its motion direction and remained on the intended path. As a result, the increased efficiency in robot motion also positively impacted the structural efficiency and energy consumption of the robot.

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1. INTRODUCTION

Along with the advancement of technology in the field of robotics, it is believed that robotics technology will undergo significant expansion, contributing to major advancements in the world of technology [1]. The current development of robotics faces a new challenge, which is the generation of robots that enhance interaction and collaboration with humans [2]. In line with this, National Achievement Center Indonesia facilitates the development of students' abilities through the contest of Robot Indonesia, aiming to prepare a golden generation. In this event, students from various universities in Indonesia compete to develop a robot for competition. The main components in robot development are sensors, robot motion control systems, and mechanics. Sensors serve as the robot's senses, transmitting information to the robot's motion control system, which functions as the brain controlling the robot's mechanics, resulting in the robot's movement [3]. The ability to navigate in complex environments is an important skill for intelligent robots [4].

In the field of robotics, the utilization of control systems, particularly in robotics, requires various equipment that falls under the hardware component of an integrated robot system, as well as software that plays a supporting role in the operation of a robot system which a capable of performing various complex activities or motions [5] in practice [6]. However, for a robot to move in a complex manner, it is necessary to accurately determine its direction so that every activity programmed for the robot can be executed as intended. Complex robot movements can lead to inaccurate distance readings. The cause of inaccurate distance readings on the robot is the change in the robot's orientation when moving, where the sensors do not face perpendicular to the wall [7]. To determine the direction of a robot, a sensor module is required that can determine the robot's direction for moving forward, turning right, or turning left based on the readings from line sensors or distance sensors installed on the robot. The sensor module used to determine the robot's motion direction is a compass sensor module. A compass sensor is an electronic sensor that provides horizontal directional information regarding the Earth's magnetic field or as a navigation direction [8]. The compass sensor module can provide data in the form of cardinal directions, and this data can be used to command the robot to move in the desired direction. To activate the compass sensor, a trigger is required from the readings of other sensors on the robot, such as line sensors and distance sensors.

The movement of a legged robot [9], especially a hexapod robot (six-legged robot), cannot be predicted with certainty due to various factors that can cause the robot's movement to deviate from its intended path or programmed direction. This was evident in the case of the DK-ONE hexapod robot representing Universitas Negeri Manado in the SAR Indonesia robot contest in 2021. In the contest, the DK-ONE robot was unable to move toward the designated room due to several factors, including unbalanced frame construction and friction between the robot's legs and the arena floor, causing the robot's legs to slip. As a result, the pre-programmed number of steps for the robot was no longer synchronized with the intended path to the target room, leading to errors or collisions within the robot's system. Therefore, there is a need for a safe and efficient collision avoidance program, which poses a challenge for every robot, especially in decentralized scenarios where the robot creates its own path [10]. Based on this problem, the researchers were interested in conducting a study with the aim of developing the motion direction of the DK-ONE robot based on a microcontroller using a compass sensor.

2. METHOD

This research aims to develop the motion direction of the DK-ONE robot based on a microcontroller using a compass sensor as the determinant of the robot's direction, triggered by inputs from analog and digital sensors on the robot. The research utilizes interview techniques to gather initial data on the issues related to the failure of the DK-ONE robot's movement. Additionally, documentation techniques or literature studies are conducted to gather information related to the development of motion in robots from books and articles in relevant journals on the development of microcontroller-based robot motion with compass sensors. The materials used in this research are as follows.

2.1. Materials

In this research, materials with specifications are used as in Table 1. These materials include Arduino and servo motors which are used to form the robot body. The acrylic board is used to form the robot frame. Jumper cables are used to assemble the robot installation network, and the power source for this robot is the battery.

Table 1. Materials of the research

No	Material Name	Quantity
1	Arduino Mega ATmega2560	1 Pcs
2	Driver Motor Servo 16 Channel PCA9685	2 Pcs
3	Motor Servo RDS3115mg	18 Pcs
4	Arduino Mega Sensor Shield	1 Pcs
5	Battery LP3 Power 2200mAh 3 Cells	1 Pcs
6	Direct Current (DC) Buck Converter 11volts to 5volts	1 Pcs
7	Acrylic Board 5mm	1 m^2
8	Male-Male Jumper Cable	28 Pcs
9	Female-Male Jumper Cable	50 Pcs
10	Female-Female Jumper Cable	60 Pcs
11	6 mm Bolt	24 Pcs

2.2. Hardware

The hardware used in this research is shown in Table 2. The tools shown in this table are used to make and assemble the robot, including drills for drilling holes in the frame or acrylic, solder to solder the jumper cable connections, and grinder for cutting acrylic boards.

Table 2. Hardware

No	Material Name	Quantity
1	Electric Soldering Iron (Murano 20-80W)	1 Pcs
2	Grinder Machine (Bosch Angle Grinder With Stand (GWS) 060)	1 Pcs
3	Drill (Cordless Impact Drill Bosch Building Border Line (GSB) 120)	1 Pcs
4	Solder Tin (Paragon)	1 Roll
5	Steel Drill Bit (Bosch 4-18mm)	1 Set
6	Spiral Drill Bit (Bosch)	1 Pcs

2.3. Software

Software is digitally programmed, stored, and formatted data with specific purposes and functions. It does not have a physical form. In this research, two software programs are used, each with its own function, namely programming software and design software. The programming software used to create the robot code in this research is the Arduino integrated development environment (IDE). Arduino IDE was chosen because it is open source, allowing it to be used and modified freely. Additionally, Arduino IDE is easy to understand and compatible with various types of microcontrollers used in this research. The design software used in this research is used to design the mechanical structure of the robot as well as the robot's schematics. The two design software programs used in this research are Autodesk Inventor and Microsoft Visio. Autodesk Inventor is used to design the appearance or shape of the robot. Microsoft Visio is used to draw the wiring network structure on the robot.

This research was conducted at the Integrated Laboratory of Electrical Engineering Education, UNIMA. The development of the DK-ONE Robot's motion utilizes the waterfall method. The waterfall method provides a sequential or sequential flow [11], starting from analysis, design, implementation or coding, verification or testing, and support or maintenance phase [12]. The waterfall stages are as follows [13].

- System analysis. It is intended to analyze the problems and development needs, as well as the solutions required to address those problems. The analysis of these needs is related to the software, hardware, and materials used in the research.
- Design. In the design stage, the researcher plans and maps out the tasks to be performed and the time required for each task.
- Coding. In this stage, the researcher develops the code that connects the existing sensors to transmit information to the robot's motion control system. In this case, the researcher utilizes Arduino IDE software based on a microcontroller to assist in the coding process.
- Testing. In this stage, after stages 2 and 3 have been completed, the implementation is carried out on the robot, followed by testing, which consists of unit testing and acceptance testing.
- The supporting or maintenance stage comes after testing. It allows for possible changes based on the testing results. In this stage, the development process can be repeated, starting from system analysis to refine the developed robot's movement, but it is not intended to create a completely new development of robot movement.

3. RESULTS AND DISCUSSION

Analysis and identification conducted on the DK-ONE robot revealed that the robot's movement often experiences errors due to the navigation system used, which only focuses on the programmed pulse width modulation (PWM) signals sent to the robot. As a result, the robot frequently encounters errors when moving, whether on a flat surface or uneven terrain. The main cause of errors during robot movement on both flat and uneven terrains is the insufficiently capable direction determination system in determining the robot's movement direction. Therefore, a new system and equipment are needed to assist in stabilizing and keeping the robot on track during operation, such as the use of sensors or control within a task framework [14]. One such system or device is the addition of an HMC8853L compass sensor to the robot system, which enables the robot to recognize its position and search for the path it traverses [15]. This sensor is used as a navigation tool to determine the direction [16] of the DK-ONE robot and guide it along its path [17], as well as to direct the robot toward its destination and perform assigned tasks [18].

Developing a natural control strategy is an interesting challenge in designing the robot interface system [2]. To ensure the effective functioning of the navigation system of the DK-ONE robot, a design is required to ensure the reliability of the system. This design phase includes the design of the system block diagram, schematic design, and mechanical structure design of the robot. The block diagram design of the robot is the initial stage in the process of creating the DK-ONE robot system. This block diagram design contains information about all the components and their interconnections used in the robot. The results of the DK One robot diagram design are shown in Figure 1.

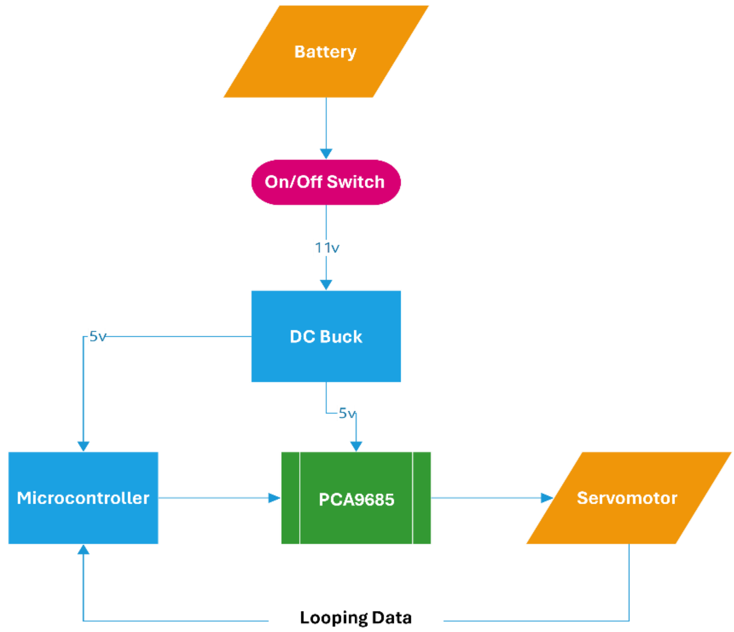


Figure 1. System block diagram

After creating the block diagram, the next step is to design the schematic of each component used in the robot. The schematic design of the robot serves to determine the connections of each component that will be used in the robot [19]. The schematic designs may include the power supply circuit schematic, the connection schematic of Arduino or microcontroller to the Arduino sensor shield, the connection schematic of PCA9685 as the servo motor controller to drive the robot from the Arduino sensor shield, and the connection schematic of the servo motors that drive the robot to the PCA9685, as shown in the Figures 2 to 5.

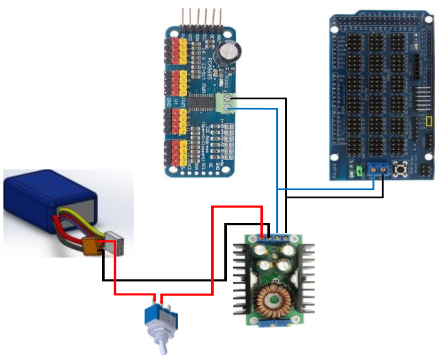


Figure 2. Power supply circuit schematic

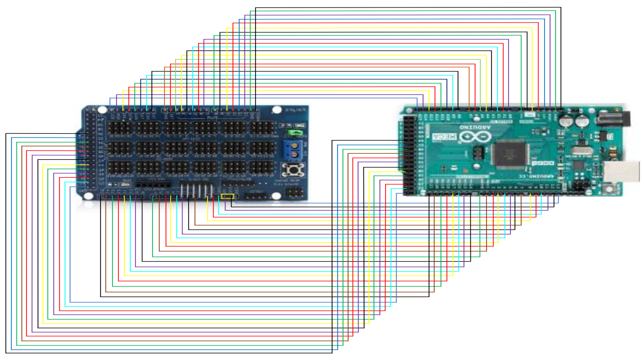


Figure 3. Connection schematic

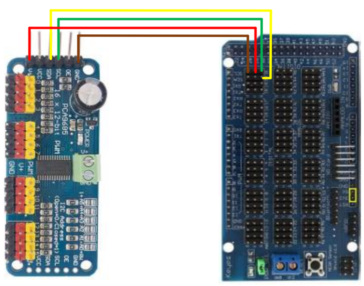


Figure 4. Connection schematic

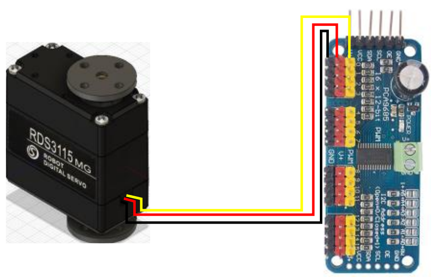


Figure 5. Schematic diagram of servo connections to PCA9685

After creating the schematic design, the next step is the mechanical structure design of the robot. The design of the robot’s structure is necessary to create an initial layout of how the robot will look and to ensure the size and mechanics of the robot during the manufacturing process. This is done to ensure precision in the construction of the robot’s structure and minimize any system failures resulting from errors or imprecisions in the robot’s structure. In the mechanical design of the robot, RDS3115 digital servos are used as the robot behavior to enable its movement. The 12 servos integrated with the program on the microcontroller, controlled by the servo driver PCA9685, allow the robot to perform movements as shown in Figure 6.

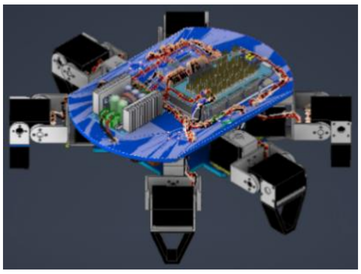
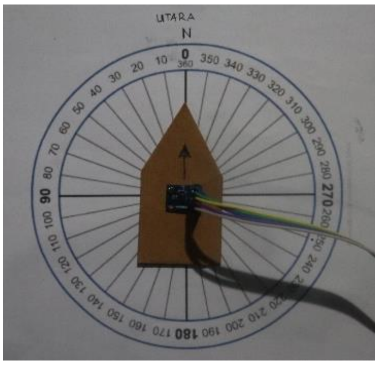
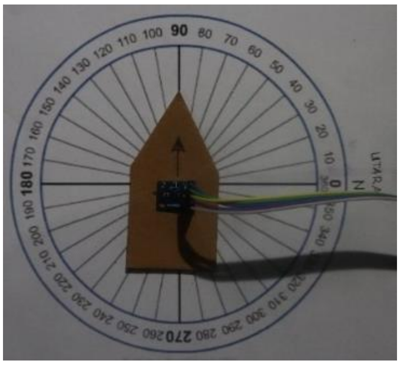


Figure 6. Mechanical motion system

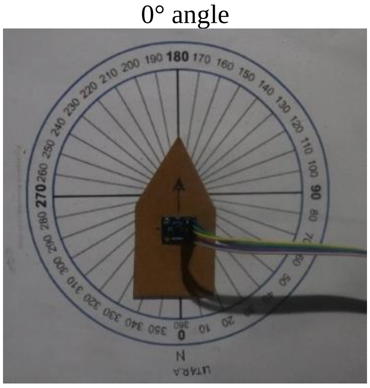
In the coding stage, the first step is to read the output of the HMC88531 compass sensor as a determinant of the robot’s movement direction and to help the robot detect systematic changes in its orientation [15]. In this process, the HMC8853L compass sensor module is connected directly to the Arduino Mega, separated from the robot body. The readings from the compass sensor can be viewed on the serial monitor in the Arduino IDE. During this stage, the sensor readings are taken by placing the compass sensor on a cardboard box that is marked with an arrow to indicate the front direction of the compass sensor [20]. The cardboard box is then placed on top of a piece of paper with lines labeled with several angles. These angle labels serve as reference representations for the north, west, south, and east directions, with the sensor’s direction being indicated at angles of 0°, 90°, 180°, and 270°. This setup can be seen in Figure 7.



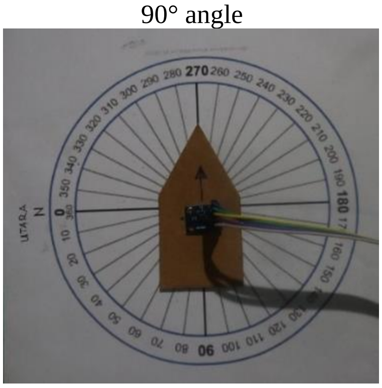
0° angle



90° angle



180° angle



270° angle

Figure 7. Sensor readings at different angles

In Figure 7, the sensor is positioned at four different angles, with each angle representing a specific direction: 0° for the north, 90° for the west, 180° for the south, and 270° for the east. From each position of the compass sensor, readings are taken and displayed on the Arduino IDE's serial monitor to match the direction or angle values on the figure with the sensor readings. To align the sensor readings with the angle directions, the sensor board is placed on top of the figure containing the angle directions. The sensor's direction is then adjusted towards the 0° angle, then the paper is rotated together with the sensor board until the sensor reading value on the serial monitor matches the 0° angle. The paper with the angle directions is then secured to prevent movement while the sensor board is rotated. The value displayed when the sensor is facing the 0° angle is recorded. Then, the sensor is rotated to the 90° angle, and the displayed result on the serial monitor is recorded again. The same process is repeated for the 180° and 270° angles. This process is repeated six times to ensure precise sensor readings for each direction. Based on the sensor readings from the compass sensor, the next step is to test these sensor values in the robot system. After performing the sensor readings at 0°, 90°, 180°, and 270° six times, the results obtained are shown in Table 3 and Figure 8.

Table 3. Results of sensor reading testing on the Arduino IDE serial monitor

Testing	Direction sensor on the paper with angle value			
	0^0	90^0	180^0	270^0
Test 1 serial monitor	0^0	89^0	180^0	271^0
Test 2 serial monitor	0^0	90^0	180^0	270^0
Test 3 serial monitor	0^0	98^0	180^0	269^0
Test 4 serial monitor	0^0	90^0	180^0	270^0
Test 5 serial monitor	0^0	90^0	180^0	270^0
Test 6 serial monitor	0^0	90^0	180^0	270^0

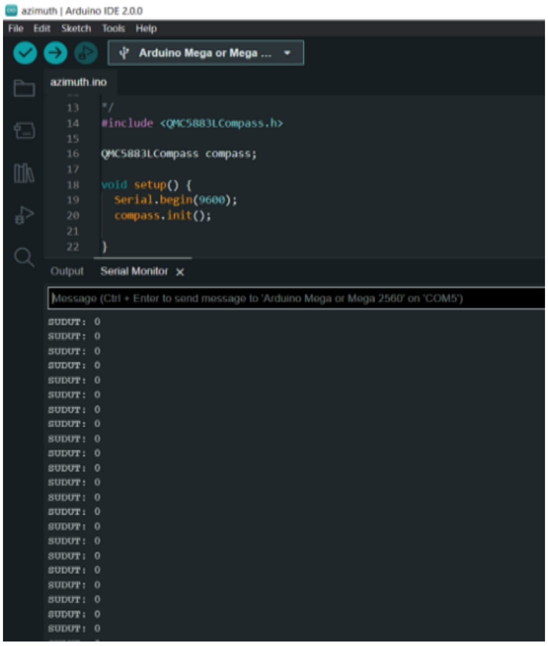
From Table 3, it can be seen that the test results show that there is a difference in the results found, namely for an angle of 270° test 1 the result is 271°. Likewise, the findings for test 3 were 269°. The difference in findings from reading angles on this serial monitor is still at a tolerable level. The sensor reading values from Table 3 can be seen in Figure 8.

From the data, it can be observed that the compass sensor readings on the serial monitor have an angle tolerance of 10-20 degrees. With such a small tolerance, it can be concluded that this sensor is suitable for navigation purposes to determine the direction of the DK-ONE robot. It can effectively maintain a constant angle direction in various assigned terrains, even in the presence of disturbances that may affect the robot's program [21].

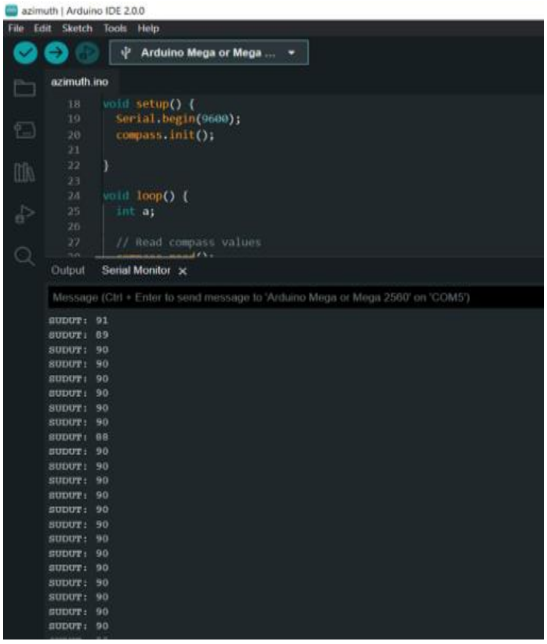
After the precision testing of the compass sensor readings is completed, the next step is to test the sensor readings on the DK-ONE robot by incorporating them into the robot's program. The compass sensor readings are used as reference values in the robot's program to ensure that it moves in accordance with the specified angle directions. The compass sensor is adopted to control the direction of the robot's movement through the microcontroller installed on the robot [22]. With the data obtained from the previous sensor testing, the robot's movement can be controlled based on the direction of the sensor placed on the robot's body. The purpose of the earlier sensor testing, in addition to ensuring reading precision [23], [24], is to use the sensor as a reference for the robot's movement based on the direction the robot is placed [25]. The reference values obtained from the compass sensor readings are used to adjust the PWM of each motor that drives the robot [26]. With these compass sensor values, the PWM values for each motor can be stabilized while the robot is moving straight or turning. To ensure that the robot stays on track while moving straight [27], two compass sensor reading preferences are used. These values are obtained by positioning the robot slightly to the left and right. The sensor readings in these positions are used as upper and lower bounds of the compass sensor values to control the robot's position and ensure stable movement when it is on a straight track.

After testing the microcontroller-based robot motion system with the compass sensor, it is necessary to perform the supporting or maintenance stage for the developed and tested system. This stage aims to ensure the reliability of the system. In this stage, repeated observations and testing are conducted on the new system. After multiple tests, it can be confirmed that this new robot system is more efficient in terms of robot movement. With improved robot movement, there will also be a positive impact on the efficiency of the robot's structure and power supply usage.

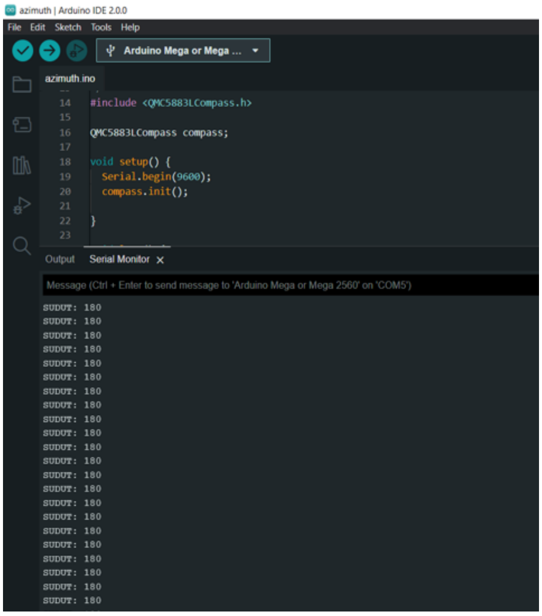
The final result of the testing reveals that the DK-ONE robot's movement has improved significantly by using the preferences derived from the compass sensor readings, which are used to determine the robot's movement direction. This development has made the DK-ONE robot's movement more stable, whether on straight, flat, or uneven tracks. The robot no longer experiences errors (wrong direction) during movement, and it stays on the intended path while walking.



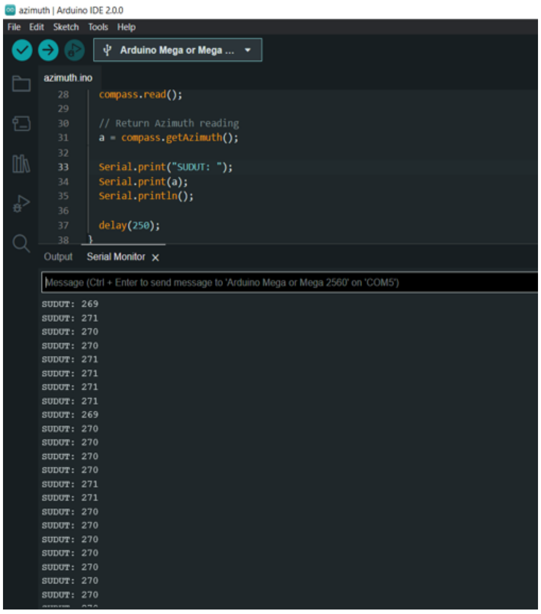
0° angle



90° angle



180° angle



270° angle

Figure 8. Sensor values at different angles on the serial monitor

4. CONCLUSION

Based on the results obtained in the research along with the discussions, it can be concluded that the HMC5883L compass sensor exhibits good accuracy, with a range of 1° to 2°. When applied to the DK-ONE robot, the compass sensor significantly improves the determination of the robot's movement direction, resulting in a more stable movement of the DK-ONE robot. The development of the robot's movement direction using the compass sensor enhances its stability during straight, flat, or uneven track navigation. The robot no longer experiences errors (wrong direction) during movement and stays on the intended path while walking. This is caused by a change in strategy. Initially the DK-One robot used a strategy of number of steps to turn, replaced by a compass sensor strategy that determines the direction of the robot's rotation. Consequently, the improved robot movement also contributes to the efficiency of the robot's structure and power supply utilization.

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